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PINUS

(pines)

Pines (*Pinus*), the most important conifers, grow around the world in the Northern Hemisphere. Southward they occur as far as Nicaragua, northern Africa, Asia Minor, and Malaya. One species crosses the Equator in Sumatra. Thirty-six of the 90 to 100 species in the world are native in the United States.

Pine trees usually have furrowed bark, resinous wood, and an upright axis which produces each year a long shoot with one or more circles (whorls) of spreading branches. Buds are large, pointed, usually resinous. The needlelike leaves are borne in clusters or bundles of mostly 2 to 5 (rarely more or only 1). They persist from 2 to 12 years in different species.

Numerous male strobili are clustered at the base of current year's growth in lower part of crown. Ovulate strobili are borne on the same tree, especially in upper part of crown, sometimes clustered near the end of the current year's growth. The woody cones may be egg-shaped or cylindrical but are sometimes oblique and not symmetrical. They mature at the end of the second year (rarely third) and may shed promptly or remain attached to the tree, sometimes not opening. Seeds are long-winged or sometimes wingless. Cotyledons 4 to 15.

Pines are separated into two groups. The soft or white pines (subgenus *Haploxylon*), have mostly soft wood and needles commonly in clusters of 5, with 1 vascular bundle in cross section. The hard pines (subgenus *Pinus* or *Diploxylon*) have mostly hard wood and needles commonly in clusters of 2 or 3, with 2 vascular bundles in cross section.

F—490470

PONDEROSA PINE (*Pinus ponderosa* Laws.)

Other common names: Blackjack pine, bull pine, pondosa pine, rock pine, Rocky Mountain ponderosa pine, western yellow pine, yellow pine, pinabete, and pino real.

Ponderosa pine is the most widely distributed pine in North America, extending from Canoe Creek on the Fraser River in British Columbia in the north, to Durango, Mexico, in the south. It is found from Holt County, Nebr. (*14*) [1] to the Pacific Coast.

Ponderosa pine extends from about latitude 51° N. and about longitude 123° W. in the Fraser River drainage of British Columbia to approximately latitude 24° N. and longitude 105° W. in west-central Mexico, and from latitude 42°30′ N. and longitude 99°30′ W. in northeastern Nebraska to the Pacific Coast in California. The southernmost range in Baja California is stated to be in the isolated peaks of the Sierra San Pedro Martir (*22*) but more recent investigations indicate the coastal southern extremity to be Julian and San Louis Rey Canyon in San Diego County (*39*). Within this vast area commercial stands are found in British Columbia, Washington, Oregon, Idaho, Utah, Montana, South Dakota, Colorado, Nebraska, New Mexico, Arizona, California, and Mexico (*116*).

The earliest published account of the species is in the journal of the Lewis and Clark expedition of 1804. David Douglas, the Scottish botanist, recorded it in 1826 as occurring on the Spokane River and a year later sent seeds to the London Horticultural Society from which a tree was raised in the Caledonian Horticultural Society's garden. The first scientific description was by Lawson in 1836 (*116*). For many years it was called western yellow pine but the name was changed in 1932 (*1*) and generally accepted thereafter.

HABITAT CONDITIONS

Climate

Ponderosa pine is found generally in a subhumid humidity province and a microthermal temperature province characterized by summer rainfall deficiency. For the east slope of the Rockies, the Black Hills, Utah, and the Southwest, however, summer rains are the rule although the Southwest regularly experiences low May–June precipitation. At selected, typical locations in six western States and British Columbia average annual precipitation varies from 10 to 21 inches and average growing season (May through August) from 2 to 6 inches. Corresponding figures for the Black Hills of South Dakota are about 28 and 13 inches respectively, but at the Fort Valley Experimental Forest near Flagstaff, Ariz., 6 inches of the total growing seasonal precipitation of 7 inches falls in July and August following the May–June dry period. The Skagit valley of northwest Washington and Challenge in north-central California where annual rainfall reaches 41 inches and 69 inches may be two of the wetter areas supporting ponderosa pine in any quantity.

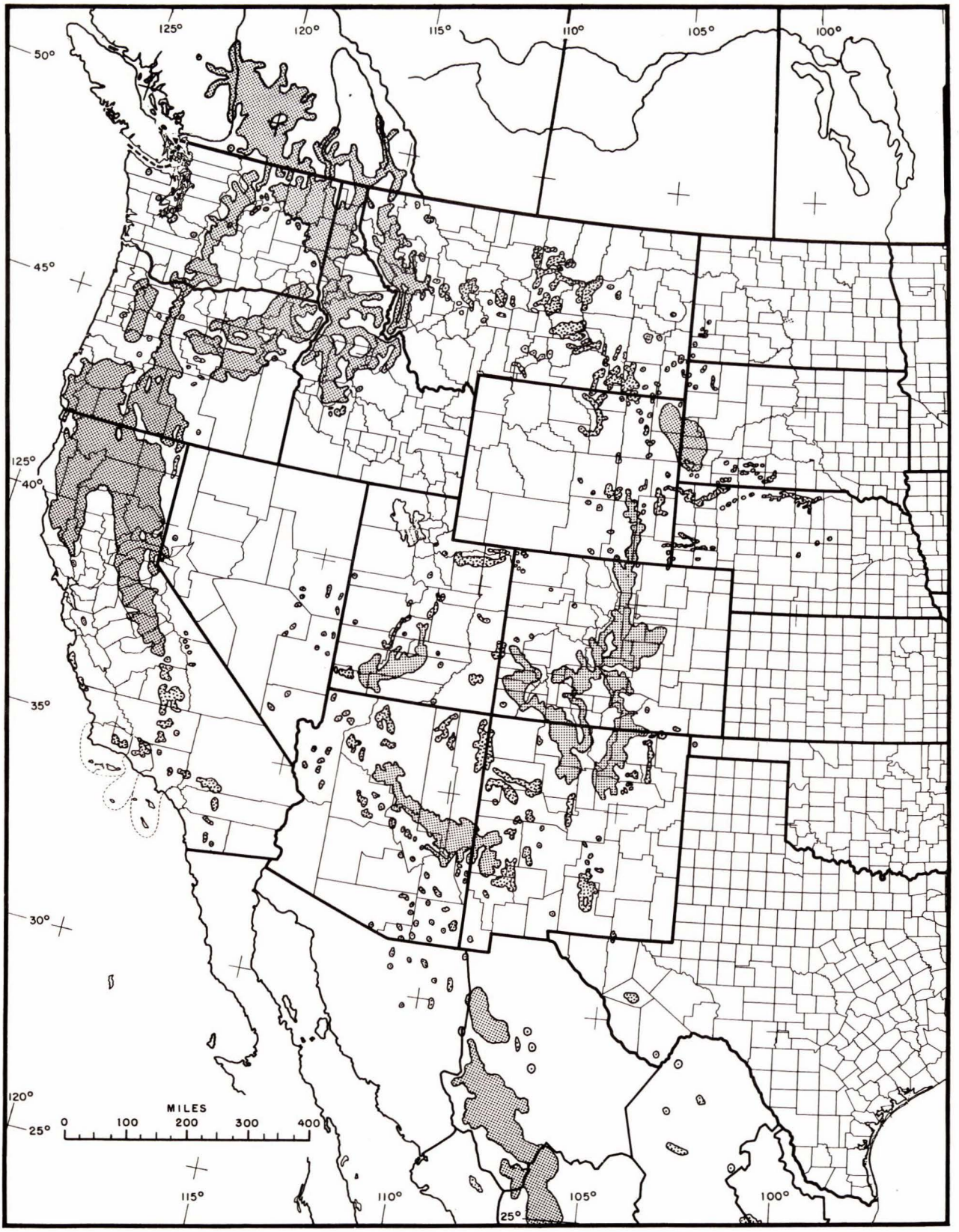
The extent of the seasonal rainfall deficiency is better appreciated when it is realized that commonly July and August precipitation is about 1 inch or less, and that in some places, as in California, it is often lacking. Summer showers probably provide scant moisture useful to young seedlings. Total growing season precipitation figures may mean little because of the distribution pattern.

Regardless of location where ponderosa pine grows, average annual temperatures are between 41.8° and 49.8° F., and average July–August temperatures between 62.0° and 69.6°. Annual extremes are from −40° to 110° or perhaps even lower and higher.

Soils and Topography

Ponderosa pine grows on soils of igneous, metamorphic, and sedimentary origin, including quartzite, argillite, schist, shale, basalt, andesite, granite, cinders, pumice, limestone, and sandstone. This results in a variety of soil types including sandy loam, gravelly loam, silt loam, clay loam, loamy sand, and gravel on which the species is found throughout its extensive range (*10*, *97*, *132*). Depending on the locality and the horizon of the samples, soils have been found to vary from pH 4.9 to pH 9.1 (*10*, *35*). Frequently the pH in the surface horizon is from 6.0 to 7.0. Soil samples to a depth of 24 inches in the Boise Basin in central Idaho were found to be nearly neutral (pH 6.6 to pH 7.3). The species probably reaches its best development on well-drained, deep sandy, gravel, and clay loams, as shown by its performance on such sites (*81*, *87*) and its frequent absence where an impervious substratum exists. Associated species as lodgepole pine, encroach when good drainage is prevented by the presence of clay subsoil (*59*). The texture of the soil mantle, and thus its moisture-retaining capacity, plays an important role in the tree's development, possibly

[1] Italic numbers in parentheses refer to Literature Cited, p. 426.



The range of ponderosa pine.

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more so than the chemical constituents (*58*, *97*, *117*).

Studies have shown strong relationships between site index and soil depth (*89*, *133*). In the Black Hills, soil depth had more influence on tree height than parent material (*89*). In Montana, ponderosa pine growth response has been related to soil type, effective soil depth, landform, and moisture availability. High water tables or seeps tend to increase site productivity regardless of the soil type and landform (*26*).

Ponderosa pine stands, 51, 75, and 78 years old, growing in coarse-, medium-, and fine-textured soils in Montana, had their greatest root development in the medium-textured soils and the least in fine-textured soils. Root concentration was more uniform in the medium-textured soil and concentration dropped off abruptly below a soil depth of 18 inches in fine-textured soils (*25*).

Evidence of the dangers of off-site planting has been shown in northern Idaho. Pondersosa pine planted on western white pine sites exhibited good growth the first few years, but subsequent growth and vigor declined, becoming progressively more apparent by 20 years of age.

On selected areas in Utah, Arizona, Colorado, and Idaho, waterholding capacities of the soil varied from 25.8 to 70.0 percent, and wilting coefficients from 3.3 to 16.1 percent (*10*).

Ponderosa pine is found at elevations from sea level near Tacoma, Wash., to about 9,000 feet in California, Colorado, and Arizona (*97*). From north to south throughout its range the species tends to grow at progressively higher altitudes and within more restricted elevational limits. In California, it is most commonly found at elevations from 500 to 3,500 feet in the north and from 5,300 to 7,300 feet in the south. The implications are that from north to south the isohyets gain altitude faster than the isotherms, thereby curtailing the elevational zone in which ponderosa pine can favorably grow (*53*). Although exceptions can be found, the best developed stands are at elevations of 4,000 to 8,000 feet on benches, plateaus, and west and south aspects.

Associated Trees and Shrubs

Ponderosa pine is contained largely within the arid transition zone of the West. Characteristically, ponderosa pine tends to grow in groupwise arrangement of age classes, particularly where it occurs in pure stands.

Ponderosa pine is an integral component of five forest cover types in the West: Ponderosa Pine—Larch—Douglas-Fir (Type 214), Interior Ponderosa Pine (Type 237), Ponderosa Pine—Sugar Pine—Fir (Type 243), Pacific Ponderosa Pine—Douglas-Fir (Type 244), and Pacific Ponderosa Pine (Type 245). The first is typical in western

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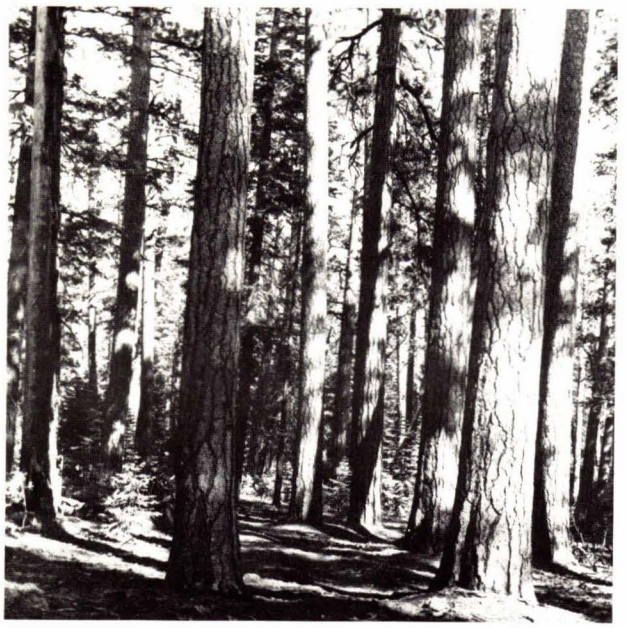
Group of immature ponderosa pines in Blacks Mountain Experimental Forest, Calif.

Montana; in this type ponderosa pine never predominates. With cutting or increase in moisture it is easily transformed into either the Larch—Douglas-Fir Type or the Douglas-Fir Type.

The Interior Ponderosa Pine Type covers the greater part of the area on which the species grows in eastern Oregon and Washington, Idaho, western Montana, South Dakota, the east slope of the Sierra Nevada in California, Utah, western Colorado, Arizona, and New Mexico. Ponderosa pine is frequently found in pure stands and elevationally is the first forest type of timber importance above the desert floor. This is commonly a climax type.

The Ponderosa Pine—Sugar Pine—Fir Type is often called the mixed conifer type in California where it is most extensive on the west side slope of the Sierra Nevada. It is characterized by the predominance of ponderosa pine, sugar pine, white fir, Douglas-fir, or incense-cedar, singly or in combination. The type is found at 3,000 to 6,000 feet elevation and is considered a climax form.

The Pacific Ponderosa Pine—Douglas-fir and the Pacific Ponderosa Pine Types are found in



F–441132

Old growth ponderosa pine in eastern Oregon on the Fremont National Forest.

northern California and southern Oregon. The former typically is found in the north coast ranges, the Siskiyou Mountains and southern Cascades; the latter on the lowermost west slopes of the Sierra Nevada and southern Cascade range and cross ranges of northern California and southern Oregon. The latter is a climax type; the former is not.

In addition, ponderosa pine occurs in these forest types.

Type no.	*Name*
209	Bristlecone Pine
210	Interior Douglas-Fir
211	White Fir
212	Larch—Douglas-Fir
213	Grand Fir—Larch—Douglas-Fir
215	Western White Pine
216	Blue Spruce
217	Aspen
218	Lodgepole Pine
219	Limber Pine
220	Rocky Mountain Juniper
229	Pacific Douglas-Fir
234	Oak—Madrone
238	Western Juniper
239	Pinyon—Juniper
246	California Black Oak
247	Jeffrey Pine
248	Knobcone Pine
249	Canyon Live Oak
250	Digger Pine—Oak

Within the ponderosa pine zone of northern Idaho and extreme northeastern Washington, the understory plant cover can be classified usefully by recognizing habitat groups. Thus, four associations (Ponderosa Pine-*Physocarpus*, Ponderosa Pine-*Symphoricarpos*, Ponderosa Pine-*Agropyron*, and Ponderosa Pine-*Purshia*) are easily discernible in which ponderosa pine predominates and in which it is a major climax species (*35*).

A variety of vegetation is found with ponderosa pine. The following lists are not exhaustive but include the more common woody shrubs in the different areas where the tree occurs:

a. British Columbia: *Artemisia tridentata, A. tripartita, Arctostaphylos uva-ursi, Purshia tridentata, Symphoricarpos albus, Rosa nutkana, Crataegus douglasii, Clematis ligusticifolia.*

b. Western Montana, Idaho, Oregon, and Washington: *Prunus virginiana, P. pensylvanica, P. virginiana* var. *melanocarpa, Artemisia tridentata, Chrysothamnus nauseosus, Ceanothus velutinus, Symphoricarpos rivularis, Amelanchier alnifolia, Purshia tridentata, Rosa spaldingi, R. ultramontana, Spiraea betulifolia, Berberis aquifolium, Physocarpus malvaceus* (*35*).

c. California: *Chamaebatia foliolosa, Arctostaphylos patula, Ceanothus cordulatus, C. prostratus, C. parvifolius, Castanopsis sempervirens.*

d. Colorado and the Black Hills: *Artemisia frigida, Purshia tridentata, Populus tremuloides, Prunus virginiana, Rosa macounii, Opulaster intermedius, Amelanchier alnifolia, Symphoricarpos occidentalis,* and *Arctostaphylos uva-ursi.*

e. New Mexico and Arizona: *Quercus gambeli* (*96*).

In eastern Washington and northern Idaho, height growth of ponderosa pine was related to several vegetation types (*37*) as follows:

I. Best: *Abies grandis—Pachistima myrsinites.*

II. Good: *Pseudotsuga menziesii—Physocarpus malvaceus; Pinus ponderosa—Physocarpus malvaceus; Pinus ponderosa—Symphoricarpus albies.*

III. Fair: *Pseudotsuga menziesii—Calamagrostis rubescens.*

IV. Low: *Pinus ponderosa—Purshia tridentata; Pinus ponderosa—Agropyron spicatum.*

LIFE HISTORY

Reproduction and Early Growth

Flowering and fruiting.—In western Montana, central Idaho, and eastern Oregon, at elevations from 3,000 to 6,000 feet above sea level, flowering

generally begins between May 1 and 10. Female conelets reach nearly 1 inch long from May 5 to June 10, pollen is shed May 25 to June 15, cones reach full size July 20 to August 10 of the following year, seed is ripe August 20 to September 5, cones begin to open September 1 to 13, and seed is shed until November. On the east and on the west side of the Sierra Nevada in California at 6,000 feet altitude, cone development takes place about 2 weeks later (*47*). In California on the west slopes of the Sierra Nevada, pollen has been collected as early as April 15 at 39° N. latitude and 121° W. longitude at 3,000 feet, but May 11 was found to be an average date for a 7-year period. For this locality it is estimated that a mean interval of 8 days per 1,000 feet difference in elevation can be considered safe for purposes of pollen collection (*38*).

In Colorado at 8,900 feet studies made over a 9-year period disclosed that carpellate flowers emerge on or about June 18 and that only about 36 percent of them were surviving at the beginning of the second year. Their initial emergence is closely correlated with the passing of freezing weather (*105*).

Seed production.—No regular periodicity has been observed in the seed production of ponderosa pine. In California medium seed crops are borne on an average of every 2 years although the average interval between very heavy cone crops is 8 years (*47*). Observation over 23 years shows the species to be a poor seeder west and a fair seeder east of the Continental Divide in Montana with only one good crop occuring during this time (*15*). The species bears cones as early as 16 years; it will continue to produce good seed when 350 years old (*31*). Seed from trees 60 to 160 years old possesses greater viability than that from younger or older trees. In California, trees over 25 inches d.b.h. were the best producers (*47*). In central Idaho, mature and overmature trees growing at 5,500 feet elevation produced lower quality seed than similar trees at 4,000 feet (*99*), and open grown trees produced heavier crops of larger cones than stand-grown trees.

The insects which do most damage to cones and to seed development are probably *Conophthorus ponderosae* and *Megastigmus albifrons* and may be responsible for considerable losses in years of small cone crops.

The seeds are consumed by a great many birds and small mammals; in years of low production the potential crop may be seriously reduced (*1*, *2*, *13*, *28*, *97*, *100*, *110*, *111*, *118*). Of particular importance are mice, chipmunks, and tree squirrels. By clipping cone-bearing twigs carrying flowers or conelets, squirrels often destroy much of the prospective cone crop (*2*, *97*, *110*).

In central Idaho ripe cones had a specific gravity of .80 to .86, and averaged 64 to 92 seeds per cone. Cleaned seed per pound varies from 6,900 to 23,000 and averages 12,000.

The mean number of seed per selected dominant for a single year in central Idaho ranged from 16,100 in 70-year-old second-growth at 5,500 feet elevation to 118,300 in virgin overmature stands at the same elevation. In California, over a 16-year period, trees 38 inches d.b.h. averaged 200 cones per tree with about 70 sound seed per cone (*47*).

Seed dissemination.—During the excellent seed year of 1958 in southern Idaho, studies of dissemination of seed into small clear-cut areas revealed that from 123,320 to 345,080 seeds per acre may reach the ground. Seedfall was 52 percent complete by September 15, and 90 percent complete by October 22 (*33*). The same year at the Pringle Falls Experimental Forest in central Oregon dissemination of seed averaged 130,000 seeds per acre along the edge of clear-cut areas compared to average seedfall of 338,000 seeds per acre within an adjacent virgin forest. Most of the seed in both instances fell within 1 or 2 chains of the parent tree (*33*). Seed was produced at the rate of 104,000 per acre in a partially cut stand in western Montana (*111*).

Ponderosa pine seed with an average weight of .058 gram fell in still air at an average rate of 5.0 feet per second (*108*).

In northwest Montana, 5 percent of the total seed production fell from the end of October of one year to the first of May of the next year (*111*), but occasionally seed is retained an even longer time (*92*). In the California pine region, trapping indicated that seed fall was complete by the middle of November (*47*). In ponderosa pine stands on the west side of the Sierra Nevada in California, cones did not open on the trees until their specific gravities had dropped below 0.62 (*107*).

Seedling development.—Throughout its range, except in the Black Hills, ponderosa pine reproduces spasmodically, which is widely thought to be the result of the chance combination of a heavy seed crop followed by an above average rainfall during the growing season. Available evidence (*22*, *29*, *46*, *67*, *97*, *98*, *103*, *132*) indicates that soil moisture is the critical factor of survival. Hence, soil texture, plant competition, and condition of the seedbed exert decisive influence in the survival of the very young seedling. There is some evidence that seedlings benefit from the proximity of moisture-holding and nitrogen-fixing plants (*22*, *88*), but these instances are the exception rather than the rule.

In these early stages of the seedling's life many factors commonly cause mortality. Cutworms (*Euxoa excellans infelix*) killed 29 percent of the seedlings in one instance (*43*). During open win-

ters 1- and 2-year-old seedlings suffer damage and killing from frost (*51*, *132*). In the Southwest, mortality from frost-heaving of seedlings less than a year old may exceed 50 percent. Damage is lessened by heavy cover and early summer germination of seed, which gives a longer establishment period (*68*, *69*). Also 1- to 3-month-old seedlings are killed by stem temperatures of about 130° F. and greater (*8*). This lethal stem temperature was produced under laboratory conditions on a sand surface by temperature some 21° higher, or about 150° (*8*). Ponderosa pine is more successful in resisting high soil surface temperature with increasing age than its competitors so that 110-day-old seedlings can successfully withstand instantaneous temperatures of 136° to 180° (*104*). At elevations of 2,760 feet above sea level and on level ground in the ponderosa pine type in California, soil surface temperatures reach 162° in July and as high as 136° as late as October 15 (*78*).

Ponderosa pine is a more extravagant user of available moisture than Douglas-fir, Engelmann spruce, or lodgepole pine, but its ability to send down a fast-growing taproot enables it to survive on and dominate the more exposed sites or other sites where competition is not high (*11*). It also possesses the ability as a seedling to withstand prolonged drought, with soil moisture content very close to, or even below, the permanent wilting point (*45*, *95*). Furthermore, on the basis of laboratory studies, dew at night might contribute to survival of ponderosa pine seedlings growing on sites where the wilting point of the soil has been reached, usually late in the growing season (*115*). Thus, by virtue of these characteristics, its lower altitudinal limits are extended beyond those of other associated species (*34*).

Some observers feel that, because of organized fire protection, a natural thinning process has disappeared and as a result, dense, even aged, stagnating stands of the species have developed. Furthermore, the invasion of associated species such as white fir, Douglas-fir, and incense-cedar have crowded out the advance reproduction and weakened the overstory of ponderosa pine, making it a prey for insects. Also when fire is excluded brush appears to invade at the expense of grass (*120*, *124*). Others believe that past fires have been instrumental in prompting the typical group appearance of small even-aged stands in this species (*97*, *127*).

The ability of ponderosa pine seedlings to send down a vigorously growing taproot has been given as a reason for its tenacity on severe sites where its associates often fail (*11*). Roots of 1-year-old seedlings reach average lengths of 22.4 inches (average top height of 2.8 inches), and 4-year-old seedlings an average maximum of 60.7 inches (average top height of 12.3 inches) on southerly aspects on cutover areas. Nevertheless, seedling mortality can be exceedingly heavy (89 percent) during the first year in selectively cut stands.

Root growth of 1-year-old seedlings was found to continue throughout the summer in both burned areas and virgin stands in central Idaho but top growth stopped by August 1. In the seedling stage, ponderosa pine, is able to maintain a more uniform transpiration rate than, for example, lodgepole pine because of its deep root system. Ponderosa pine thus has a distinct advantage over some of its shallower rooted associates (*48*).

In central Idaho soil moisture remained above the wilting point at depths below 6 inches on areas free of competing vegetation throughout the growing season but dropped to or below that critical point on most vegetated plots. The importance of competing vegetation as a deterrent to early survival and development of young seedlings has been clearly demonstrated in the Southwest (*97*).

Although ponderosa pine seedlings can withstand overstory shade and root competition for as long as 40 years, it is considered an intolerant species (*9*). Normal growth is hindered by less than 40 percent of full sunlight, and later the form and quality of seedlings are profoundly affected by the amount of side shade they receive (*97*).

On the western slopes of the Sierra Nevada, height growth of ponderosa pine started very significantly later with each rise of 2,000 feet in elevation, and the length of the growing season was significantly shorter with a 3,000-foot increase in elevation. Rates of height and radial growth did not vary with elevation during the grand period of growth. At 5,000 feet elevation a 6-year average showed that ponderosa pine started radial growth on March 23 and height growth on April 26. The former period lasted 177 days; the latter, 97 days (*44*). Ponderosa pine started height growth before sugar pine, incense-cedar, and white fir, but not lodgepole pine.

Deer sometimes eliminate the very young seedlings from a stand (*91*). Squirrels and porcupines also attack saplings and poles and, while rarely killing them, deform the stems on which they feed (*32*, *97*, *100*).

Uncontrolled fire in central Idaho was found to destroy 87.5, 85.6, and 61.2 percent of the reproduction in virgin, cutover, and young-growth stands, respectively (*21*). Even controlled burning has been found exceedingly harmful to the smallest size classes (*49*).

In the absence of regulated grazing, sheep and cattle have damaged reproduction by trampling, bedding, and occasional browsing (*97*, *109*).

Ordinarily, ponderosa pine is hardy to severe winter temperatures (*94*), but occasionally it will suffer "winter killing" of foliage if sudden drops in temperature occur. Ecotypes of ponderosa pine east of the Cascades in Washington and in northern Idaho appear to be more resistant to severe

F–370512

Reproduction and understory vegetation absent in ponderosa pine stand burned lightly for many years.

winter temperatures than ponderosa pine on the west side of the Cascades in Washington (*36*). In the Inland Empire, progenies from localities with a wide range in temperatures were most resistant to frost damage (*112*).

Vegetation reproduction.—Ponderosa pine does not reproduce naturally by vegetative means. Propagation of the species by cuttings has been accomplished but is considered still in the experimental stage. Success of rooting with various media and treatments has varied between 0 and 68 percent (*85*).

Ponderosa pine has also been propagated vegetatively by grafting. Successful intraspecific grafts of the genus *Pinus* have been achieved with ponderosa pine as the scion and as the stock (*84*).

Sapling Stage to Maturity

Growth and yield.—Ponderosa pine grows to impressive size; stems 103.5 inches d.b.h (*4*), and 232 feet in height have been recorded, and diameters of 30 to 50 inches and heights of 90 to 130 feet are common throughout most of its range. Overmature trees often reach ages of 300 to 600 years, and a tree 726 years old has been accurately determined in eastern Oregon (*60*).

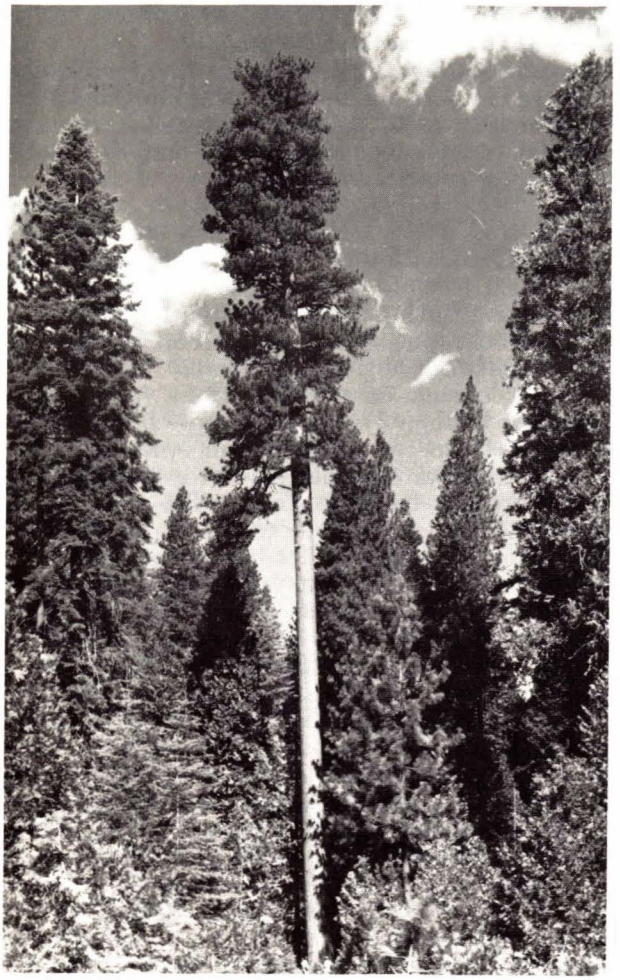
Site indices for ponderosa pine range from 40 to 160, based on height in feet for dominant trees at age 100. Representative yields of ponderosa pine from a normal yield table (*81*) for sites 70 to 100 are given in table 1. The yields should be reduced by percentages of 50 or more because of the common understocking that exists in natural stands (*27*).

TABLE 1.—*Board-foot volume* [1] *per acre, Scribner rule, of trees 11.6 inches and larger in diameter*

Age (years)	Volume per acre by site index [2]			
	70	80	90	100
	Board feet	*Board feet*	*Board feet*	*Board feet*
110	16, 200	23, 100	31, 100	40, 600
120	19, 000	26, 200	34, 700	44, 600
130	21, 500	29, 000	38, 000	48, 300
140	23, 700	31, 500	40, 900	51, 700
150	25, 700	33, 800	43, 600	54, 800
160	27, 500	35, 900	46, 100	57, 600
170	29, 200	37, 800	48, 400	60, 100
180	30, 900	39, 600	50, 500	62, 400

[1] In 16-foot logs to 8-inch top, exclusive of 2-foot stump, measured to nearest 100 board feet.

[2] Site index defined as height in feet for dominant stand at age 100 years.



F–475134

Ponderosa pine, 74 inches in diameter and over 200 feet tall on Eldorado National Forest, Calif. Known as the "Bankers" tree.

Overly dense and stagnated stands of ponderosa pine represent a serious problem on the east side of the Sierra in California, the Southwest, Washington, Oregon, northern Idaho, western Montana, and the Black Hills of South Dakota (*23*, *24*, *75*, *90*, *113*, *119*, *125*, *126*). Stunting and stagnation is most prevalent on poor sites. In northern Idaho, stunting occurs on site indices of 75 or less if stocking exceeds 100 percent (*75*). In 20- to 55-year-old ponderosa pine stands in Arizona, stagnation begins at approximately 6,000 stems per acre. Total basal area growth per acre increases with density up to about 4,000 stems per acre, and then declines. Maximum growth yield per tree is found in densities of 150 to 400 trees per acre (*23*).

On the best sites ponderosa pine is capable of growing at exceptionally fast rates. Growth of young stands on small plots in bottom land areas of northern Idaho was found to average more than 1,000 board feet per acre per year over a 17-year period (*73*). More typical of average growth of young trees, however, are the rates shown (*74*) for stands in the Inland Empire (table 2).

TABLE 2.—*10-year volume growth per tree in cubic feet for average sites*

Diameter (inches)	Age in Years			
	40	50	60	70
	Cubic feet [1]	*Cubic feet* [1]	*Cubic feet* [1]	*Cubic feet* [1]
8	3. 50	2. 38	1. 80	1. 46
9	5. 40	3. 77	3. 00	2. 50
10	7. 45	5. 25	4. 20	3. 63
11	10. 40	6. 70	5. 30	4. 50
12	-------	8. 90	6. 95	5. 90
13	-------	11. 20	8. 80	7. 50
14	-------	-------	10. 30	8. 80
15	-------	-------	12. 60	10. 70

[1] Includes stump and top without bark.

Old-growth ponderosa pine produces clear, high grade lumber, but young trees are typically limby. Natural pruning develops slowly. An average clear length of only 11.5 feet was recorded in 250-year-old stands in central Idaho.

Reaction to competition.—Ponderosa pine is classed as intolerant, being more tolerant than western larch but less tolerant than most of its associates, such as Douglas-fir, sugar pine, white fir, incense-cedar, grand fir, and western white pine (*9*).

Ponderosa pine has the ability to respond to release regardless of age (*30*, *41*, *61*, *64*, *65*, *80*, *86*, *97*). It is generally accepted that this ability, at least in the older trees, results from increased moisture supply rather than crown expansion.

Principal enemies.—At least 108 species of insects attack the previously recognized Pacific Coast form of ponderosa pine and 59 species attack the previously recognized Rocky Mountain form. The most important of the tree-killing insects are several species of *Dendroctonus*. The western pine beetle (*D. brevicomis*) is a common cause of mortality in overmature, decadent trees, but it can also kill apparently health trees of all age classes (*131*). The Black Hills beetle (*D. ponderosae*) is the most aggressive and destructive enemy in the central Rocky Mountain Region. During the 1895–1908 outbreak in the Black Hills of South Dakota, this insect killed between 1 and 2 billion board feet of ponderosa pine (*12*). The mountain pine beetle (*D. monticolae*) is an equally aggressive insect but perhaps not quite as frequent in attack (*42*). *D. barberi*, *D. convexifrons*, and

D. valens are additional important species of the genus.

The California flatheaded borer (*Melanophila californica*) is found in Idaho, Washington, Oregon, California, and Nevada. The insect is capable of killing merchantable trees but is commonly considered to be a secondary pest. Nevertheless, the annual loss from this insect is estimated to be 30 million board feet in California (*77*).

Many additional species of bark beetles and flatheaded and roundheaded borers attack ponderosa pine. Most of them enter weakened trees; but thrifty, vigorous trees are not always immune.

Several defoliating insects such as the pine butterfly (*Neophasia menapia*), the pandora moth (*Coloradia pandora*), and sawflies (*Neodiprion* spp.) periodically cause damage over extensive areas, an example of which was the recent outbreak of the pine butterfly in central Idaho (*93*).

The pine reproduction weevil (*Cylindrocopturus eatoni*), a native insect of California, usually attacks seedlings from 1½ to 3 feet in height and is probably always responsible for a limited amount of loss in natural regeneration. In one instance, a 3,000-acre plantation of ponderosa and Jeffrey pine was destroyed by this insect. So far, this pest has been recorded only in California (*52*).

One of the more insidious pathogens attacking ponderosa pine is a root and butt rot, *Fomes annosus*. It attacks trees of all ages and is difficult to detect in the case of stems other than small ones that die. It is often mistaken for the work of *Dendroctonus* beetles which invariably follow the killing of the cambium near the ground level (*123*).

Polyporus anceps is a major cause of defect in merchantable stands of ponderosa pine in Arizona, New Mexico, and the Black Hills of South Dakota. It enters its host through dead branches, and may result in a 15-foot column of rot in 150-year-old trees, with considerable cull (*6*).

Dwarfmistletoe (*Arceuthobium vaginatum* forma *cryptopodum* in the Southwest, and *A. campylopodum* forma *campylopodum* in California and the Northwest) causes more damage to ponderosa pine than any other disease (*62*). Annual mortality losses in Arizona alone total from 55 to 75 million board feet (*6*). The parasite attacks ponderosa pine regardless of age and achieves its greatest development in the most vigorous host (*55*). Infestations in the Southwest are heaviest on ridges and at middle elevations (*54*). Erect needles may increase individual tree susceptibility (*106*). This disease causes increased mortality, reduces quality of timber, and lowers seed production (*56*) and seed quality (*62*). Height, diameter, and volume growth may be reduced substantially (*56*). Severe infestations are the result of continuous intensification of the parasite for long periods of time (*62*). Diseased seed can infect trees up to a distance of 70 feet (*50*).

A needle blight, *Elytroderma deformans*, first observed in parts of Idaho, Washington, and Montana in 1913 (*130*), is found over the entire commercial range of ponderosa pine and is capable of slowing growth and killing trees of sawtimber size. Bark beetles are prompt to attack infected trees (*72*). Severe damage was reported on the Ochoco National Forest in Oregon where 98,148,000 feet of dying and dead trees were removed (*71*) during the period 1946 to 1950.

Ponderosa pine is subject to several blister rusts. The paintbrush blister rust (*Cronartium filamentosum*) common in the Southwest (*97*) and in southern Utah (*82*) may attack the base, middle, or top of the tree crowns, and spread upward and/or downward rather slowly, eventually killing many merchantable stems. The western gall rust (*C. coleosporioides*) can deform or kill seedlings and saplings. It has been found to kill occasional trees and deform larger stems in a 50- to 175-year stand in an isolated area of western Montana (*70*). *Cronartium commandrae* is present in all States west of the Rocky Mountains, but is most common in California, Idaho, Montana, Utah, and Wyoming. This rust produces understocking in seedling, sapling, and pole-sized stands in northeastern California and occasionally causes severe losses in other localized areas (*79, 83*).

Basal fire scars are common on the thick-barked stems in old-growth ponderosa pine forests. Uncontrolled fire must have been common before the advent of the white man. It has been established that fire has occurred at 8- to 10-year intervals in the ponderosa pine forests of California, Oregon, and Washington since the middle of the 16th century (*23, 121*). On the Blacks Mountain Experimental Forest in northeastern California, dating of fire scars showed that fires had occurred irregularly back to at least the 15th century. Studies on the Modoc National Forest in California revealed extensive but less damage by fire scarring to ponderosa pine than to incense-cedar, and also fewer enlargements of old fire lesions (*66*).

Six years after a fire in Arizona, no poles and only 5 percent of the sawtimber-size trees were living if more than 60 percent of the crown had been destroyed (*57*). In general, when 50 percent or less of the crown is scorched, there is little detrimental effect on survival and growth of the tree. Low tree vigor and cambium damage increase the likelihood of mortality (*76, 122*). Vigorous young trees have, on occasion, survived 100 percent crown scorch. Because buds are protected by thin long scales, late season fires cause less mortality. Continued accumulation of food reserves after diameter growth ceases in late summer also increases the ability of the tree to with-

stand fire injury. Young, fast-growing trees on good sites have the best chance of survival and old, slow-growing trees on poor sites the poorest chance of survival (*122*).

For the 11 most silviculturally important conifers of the Northern Region, ponderosa pine ranks second in fire resistance, and is indicated as "very resistant," exceeded only by western larch. For 13 important conifers of Oregon and Washington, it is rated third behind western larch and Douglas-fir (*114*.)

Ponderosa pine is usually considered a wind-firm species; its taproot generally persists throughout its life and at times strong laterals extend from the base of the tree as far as 150 feet (*132*). Windthrow occurs when root rots have weakened the tree's stability. In order of decreasing resistance, the species has been rated second out of 10 of the most important Northern Region coniferous species and is exceeded only by western larch.[2] Wind and lightning are nevertheless the two most serious sources of damage to trees of sawtimber size (especially over 30 inches d.b.h.) in the Southwest (*97*) where, on limestone sites, the root systems are apparently shallow.

RACES AND HYBRIDS

Although ponderosa pine includes a number of geographic races over its widespread range, only one variety (*Pinus ponderosa* var. *arizonica*) is recognized. The Rocky Mountain form, designated as *P. ponderosa scopulorum*, as contrasted to the Pacific Coast form, occurring east of the Continental Divide in the Central Plateau of western Colorado, Utah, eastern Nevada, Arizona, and New Mexico, is believed by some to be a true variety because of anatomical or morphological differences (*63*, *97*). Other investigators consider these differences purely a result of environment and adaptation (*116*).

It has been shown that, at least in the early years of a tree's life, races of ponderosa pine grown from seed collected from different geographical zones exhibit recognizable characteristics such as vigor and growth rate (*7*). If these characteristics are measured in respect to temperature and photoperiod treatments, they can be correlated with geographic sources (*16*).

In northern Idaho, a study of progeny from seed of different geographical zones showed, after 25 years, that where these geographical zones are delimited by annual precipitation, other characteristics such as number of needles in the fascicle, needle length, internal needle structure, and growth rate, can be considered as being inheritable (*128*). After an additional 20 years, it was found that seasonal precipitation and April-May temperatures accounted for 76 percent of the variation in progeny height growth. Seasonal distribution of precipitation was more important than total precipitation (*112*).

Elevational variation has been studied in California. Seed collected from trees growing from 125 to 7,000 feet was planted at altitudes of 960 feet, 2,730 feet, and 5,650 feet above sea level. After 20 years of growth, the fastest growing progenies at the 960-foot and 2,730-foot elevation plantations were individuals from parent trees growing at 1,000- and 2,000-foot elevations, respectively. They were taller than progenies from very high or very low elevations. In all cases the seed source nearest to the trial plantation grew the best (*20*). Seed crop year, elevation of seed source, germination time, and height growth are detectable in 2-year-old seedlings (*19*).

Results from a 45-year-old provenance study in northern Idaho and a 30-year-old study in Oregon and Washington showed that 36 percent of the variation in the height of the trees was associated with the source of seed. A clinal variation was evident in the increase of height from sources in an east to west direction. This variation was found to be related to September through June precipitation. Clinal variation in a latitudinal or altitudinal direction was related to April–May temperatures. Incidence of animal damage and of frost injury were also related to source of seed (*112*).

Also, the rate of germination of seed at different temperatures was found to vary for seed from the Southwest, the Rocky Mountains area, and the Pacific Northwest. The temperature optimum for the last area was higher than that of the other two areas (*18*).

A number of successful hybrids have been produced by crossing ponderosa pine with other races and species including *Pinus montezumae*, *P. ponderosa scopulorum*, *P. ponderosa arizonica*, *P. washoensis*, *P. latifolia*, and *P. jeffreyi* (*40*, *101*, *102*, *129*).

Progenies of intraspecific ponderosa pine crosses revealed genetical variations in their susceptibility to the pine reproduction weevil (*Cylindrocopturus eatoni*). Susceptibility was associated with geographic source of the pollen and the individual tree used as a seed parent (*17*).

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